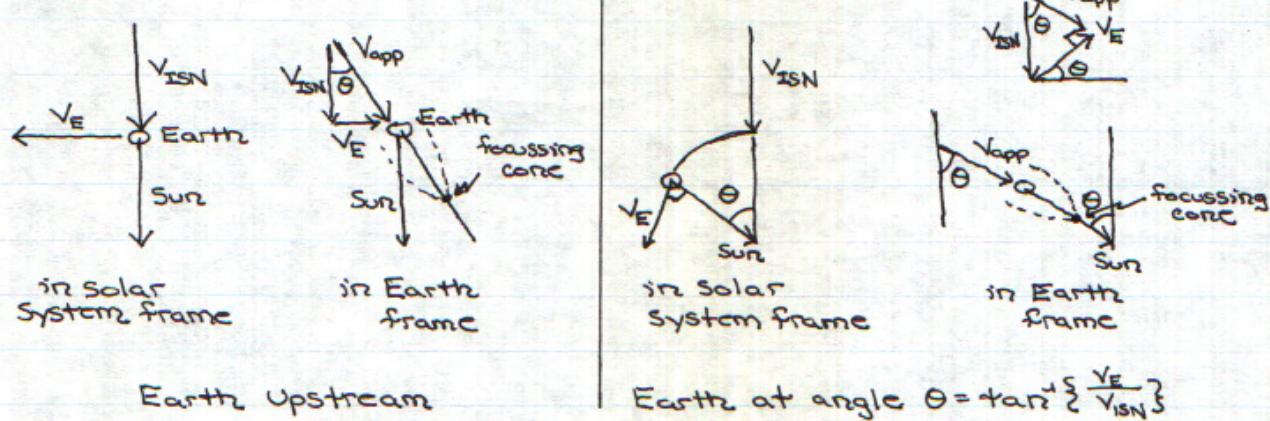


## Thoughts on the Earth Focussing Cone.

5 February 2003

### Motivation

- For  $u \sim 1$ , the force of radiation pressure and gravity approximately cancel. Therefore, near the Earth, the dominant force on particles will be the Earth's gravity. In analogy to the interstellar neutral helium, this will result in a focussing cone downstream of the Earth that will interact with the solar wind creating neutral solar wind. However, this stream of ~~is~~ neutral solar wind will only be observed ~~at~~ at the Earth when the Earth, the focussing cone, and the Sun are collinear because the solar wind propagates radially.



- Because the Earth moves at about 30 km/s, comparable to the interstellar neutral flow, in the upstream region in the frame of the Earth, the focussing cone will form an angle  $\theta = \tan^{-1} \left\{ \frac{V_E}{V_{ISN}} \right\}$  with respect to the solar wind flow and solar wind charge exchange with the focussing cone will not be observed at the Earth (see diagrams on left in figure above).

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- However, when the Earth has orbited an angle  $\theta$  beyond the upstream point, then the apparent velocity of the ISN stream in the frame of the Earth creates a focussing cone aligned with the Sun and the Earth. This will be the condition most conducive to observing neutral solar wind at the Earth because the solar wind will traverse the axis of the focussing cone on its way to be observed at the Earth, the dramatically enhanced density due to the focussing cone structure providing very high NSW fluxes.

### Expected Angle

- The value of  $V_{ISN}$  at the Earth, neglecting the energy gain due to the Earth's gravitation, which may be substantial, is given by  $V_\infty^2 = V_{ISN}^2 - \frac{890 \text{ AU} \cdot (\text{km/s})^2}{1 \text{ AU}} (1-\mu)$  (1)
- $$V_\infty = 25 \text{ km/s} \quad (2)$$
- $$V_{ISN} = \sqrt{890(1-\mu) + 625} \text{ km/s} = \sqrt{1515 - 890\mu} = 29.8 \sqrt{1.70 - \mu} \text{ km/s} \quad (3)$$
- $$\tan \theta = \frac{30 \text{ km/s}}{29.8 \sqrt{1.70 - \mu} \text{ km/s}} = \frac{1}{\sqrt{1.70 - \mu}} \quad (4)$$

For  $\mu=0$ ,  $\theta=37^\circ$ ;  $\mu=0.8$ ,  $\theta=47^\circ$ ;  $\mu=1.2$ ,  $\theta=54^\circ$ . However, these angles are upper limits because  $V_{ISN}$  will be higher by some amount due to the Earth's gravity.

### Temperature of Interstellar Hydrogen

- The angular width or, equivalently, the duration in days of the neutral solar wind enhancement due to the Earth's focussing cone is due primarily to the thermal spread of the ISN flow allowing some part of the distribution at a range of angles to satisfy the collinearity condition.

- Therefore, with the Earth at an angle  $\alpha$  with respect to the peak NSW flux (at an angle  $\theta$  with respect to the upstream), the ISN neutrals must have a velocity  $v = v_{\text{ISN}} \tan \alpha$  in the plasma frame to penetrate directly along the line connecting the Sun and the Earth and satisfy the necessary condition to charge exchange and be observed as NSW. Because the density of these particles in the plasma frame is

$$f \sim e^{-\frac{v^2}{2} \frac{v_m^2}}, \quad (5)$$

we expect the NSW flux to vary roughly in proportion to the density of those neutrals flowing directly downstream or

$$\Phi \sim e^{-\frac{v_{\text{ISN}}^2 \tan^2 \alpha / 2 v_m^2}{(M \tan \alpha)^2}} = e^{-(M \tan \alpha)^2 / 2}, \quad (6)$$

where  $M$  is the ISN mach number. Fitting the LENA NSW observations to this functional form (see Figure 1) provides an excellent fit to the data with a Mach number of 1.4. Using a value of 21.1 km/s, this implies a  $v_{\text{ISN}} = 15.1$  km/s which is  $T = 13,600$  K.

### Estimated NSW Flux

- The asymptotic ISN H density is  $0.1 \text{ cm}^{-3}$ , but only a small fraction, about 7% makes it into 1 AU with  $\mu = 1.0$ .
- Looking at the Holzer model (see Figure 2), it looks like the focussing can give enhancements of a few hundred.
- Looking at the Holzer model (see Figure 3), the scale length can be easily a few hundred  $R_E$ , say  $300 R_E$  (without help from radiation pressure, the Earth's gravity dominates out to  $L_1 \sim 230 R_E$ , so this may be conservative).
- The fraction of the solar wind that is neutral goes as

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$$\frac{\Delta P_{SW}}{P_{SW}} \sim n_H \sigma' \lambda \quad (7)$$

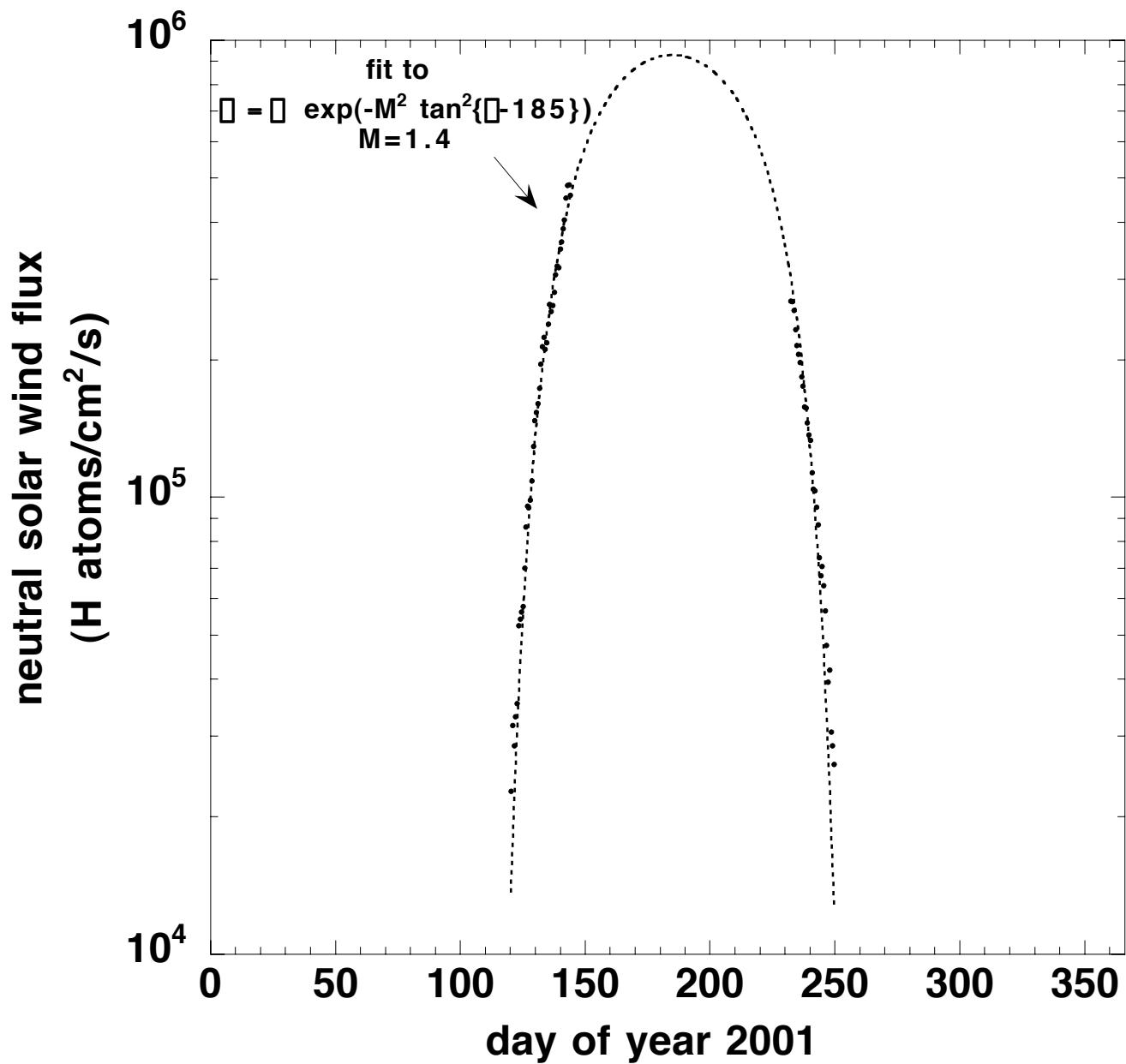
where  $n_H \sim 0.1 \text{ cm}^{-3} \cdot 0.1 \cdot 300 = 3 \text{ cm}^{-3}$   
 $\uparrow$   
into 1 AU       $\uparrow$  focussing cone enhancement

$$\sigma' = 2 \times 10^{15} \text{ cm}^2$$

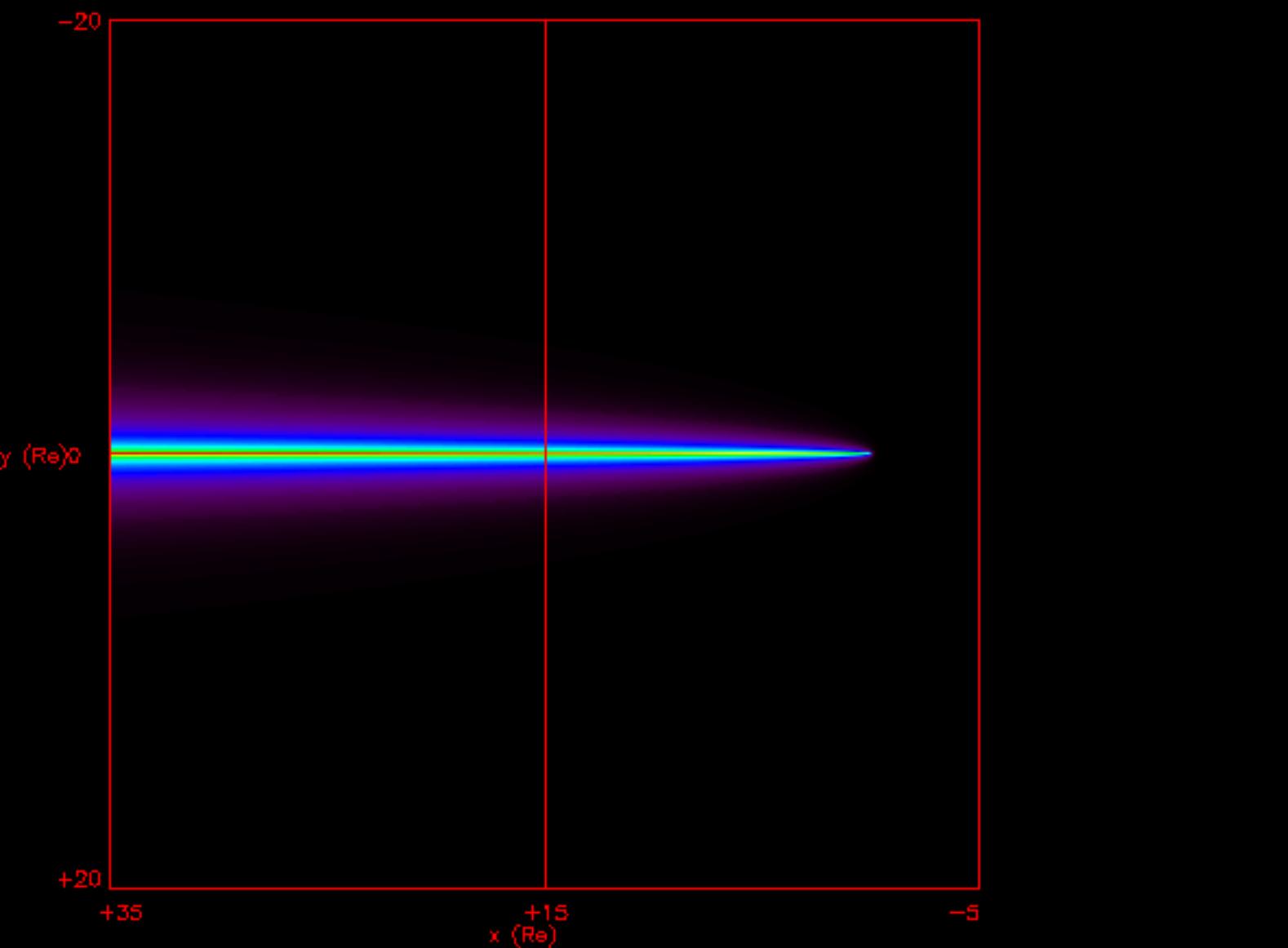
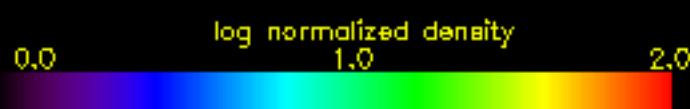
$$\lambda = 300 R_E = 300 \cdot 6371 \cdot 10^3 \cdot 10^2 \text{ cm} = 2 \times 10^{16} \text{ cm}$$

$$\frac{\Delta P_{SW}}{P_{SW}} \sim 3 \text{ cm}^{-3} \cdot 2 \times 10^{15} \text{ cm}^2 \cdot 2 \times 10^{16} \text{ cm} \sim 10^{-3} = 0.1\%$$

We observe about 0.2%, so this is reasonably consistent.

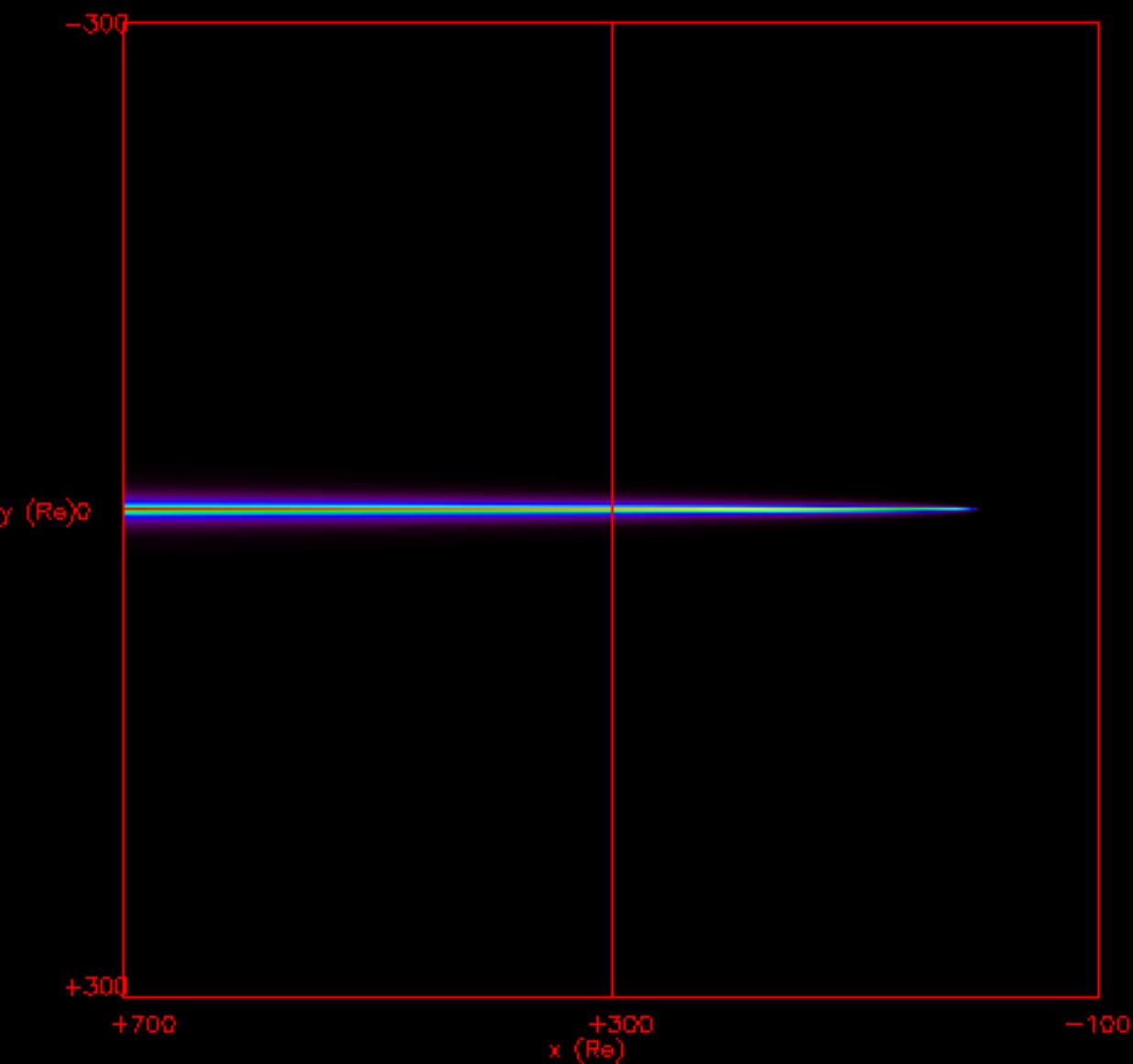
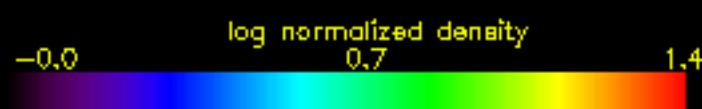


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Holzer model [1977]  
 $GM = 62.9 \text{ Re}^2 (\text{km/s})^2$ ,  $\mu = 0.0$ ,  $\beta\eta = 0.0$

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Holzer model [1977]  
 $GM = 62.9 \text{ Re}^2 (\text{km/s})^2$ ,  $\mu = 0.0$ ,  $\beta\eta = 0.0$

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